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14. ABSTRACT One of the limitations of the current generation of synthetic forces is their lack of situation awareness and understanding (Pew and Mavor, 1998). Situation awareness is critical for making intelligent decisions—without it there is no context for adapting one's behavior to accommodate the current and future states of the world (Klein, 2000; Waag and Bell, 1997). Endsley (1988, 2000) points out that situation awareness has three components: perception, comprehension, and prediction. Building on these ideas, we developed techniques for improving the situation awareness in synthetic helicopter pilots for the ModSAF military simulation by giving them more human-like perception and attention, the ability to recognize and understand battle formations and echelons, and the ability to make short-term predictions about the movements of vehicles through complex terrain.					
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Adaptive Synthetic Forces

Research & Study

for the

Office of Naval Research

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to the

**Information Sciences Institute
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UNCLASSIFIED

1. Introduction

Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.

Endsley (1988, 2000)

One of the limitations of the current generation of synthetic forces is their lack of situation awareness and understanding (Pew and Mavor, 1998). Situation awareness is critical for making intelligent decisions—without it there is no context for adapting one's behavior to accommodate the current and future states of the world (Klein, 2000; Waag and Bell, 1997). Consider a helicopter pilot who is performing a reconnaissance mission in an area behind enemy lines. The pilot must combine safety from enemy fire (by staying close to the ground and scanning for enemy air defenses), and safety from colliding with the ground and other helicopters, while simultaneously scanning for and assessing the activity of enemy units. To accommodate the competing needs of these tasks, the pilot continuously adjusts the helicopter's flight path. To avoid hitting the ground or other aircraft, the pilot tracks the helicopter's location and trajectory, the location of the terrain, and the trajectories of the other aircraft. To avoid detection by the enemy the pilot stays in areas that provide cover and concealment, but which also afford the ability to track enemy units. Once the pilot locates the enemy forces he then maneuvers so that he can observe the vehicle formations to the largest possible extent while still maintaining concealment.

All three aspects of Endsley's definition of situation awareness (Endsley, 1988,2000) are present in this example. First, the pilot has to *perceive* the elements in the environment—situation awareness is not possible without perception. The pilot would be flying blind if he or she did not acquire periodic updates about the helicopter's state, the terrain and the people and vehicles in the environment. But the ability to perceive is limited in nature—humans have a limited field of view and can only attend to a few objects at a time. To compensate for this limitation, the perceptual system must have a means of focusing *attention* on some objects while filtering out the details of others. Furthermore, perceiving involves knowing where to look and how long to look at an object before shifting attention to another.

Second, merely perceiving the elements in the environment is not sufficient—the pilot must also *comprehend* the meaning of what is occurring in the world. The pilot's mission, goals and tasks provide the context for assigning meaning to the situation. The situation must be assessed with respect to the latest perceptual inputs—is the adjacent helicopter in this formation on a safe course? Are the opposing forces moving in a column formation down a road? Or are they in a defensive position? What kind of force is it—primarily tanks, or is it a group of trucks loaded with troops? What echelon is being deployed? To answer these questions involves integrating what has been perceived over time and interpreting it with respect to known patterns of behavior. If a pattern is recognized, it can be used to infer the plans and goals of the forces under observation.

Finally, after a situation has been assessed and integrated with what was previously known, the model can then be used to *predict* what will happen in the future. Predictions are the basis for forming *expectations* about how the situation will evolve (Dominguez, 1994), which potentially inform the perceptual focus of attention in two ways. In the near term a prediction allows one to ignore (i.e., not observe) certain objects

2. Research Summary

The research performed under this grant from the Office of Naval Research (ONR) addressed situation awareness by building models in virtual humans. A virtual human is a program that models human cognition and behavior in a simulation of reality. Virtual humans are playing an increasingly important role in military battle simulations, commercial computer and video games, interactive narrative in the entertainment domain, and for human factors analysis in engineering. This section of the report summarizes our work to create greater situation awareness in virtual humans in three areas: perception, comprehension, and prediction.

2.1 Perception

Our model of attention is based on psychological principles: (1) Attention controls perceptual processing – it is the system for controlling the way information is routed and for controlling processing priorities (Posner, 1987). (2) Perceptual processing occurs in stages. (3) Attention is selective – it focuses on objects or locations, which requires the ability to filter out excess information. (4) Top-down and bottom-up processes influence attention. (5) Attention operates like a zoom lens – it can focus on a small area with high resolution or a larger area with lower resolution.

2.1.1 Perceptual Attention

We developed a model of perceptual attention for synthetic helicopter pilots in an entity-level battlespace simulator called ModSAF¹ (now known as OneSAF). The pilots were implemented in Soar, a well-known computational model of cognition (Laird et al., 1987; Rosenbloom et al., 1991, 1993). Early versions of the pilots would often crash their aircraft when they encountered situations where there were many other entities in the field of view. The reason they lost control was because they were, in a sense, paying attention to everything in the world at a high level of detail, which was both computationally expensive and humanly unrealistic. To avoid being overwhelmed by visual stimuli, what was needed was the ability to selectively focus perceptual attention on only the details that were necessary, while either leaving out other details, or else perceiving them at a more abstract level.

2.1.2 Stages of Processing

Perceptual processing is performed in stages, with perceptual (gestalt) grouping occurring in the pre-attentive stage along with some filtering, and more detailed processing in the attentive stage. The control of attention is primarily goal-driven, but attention can be captured by stimuli such as the abrupt onset caused by explosions, motion, and salient

¹ ModSAF stands for Modular Semi-Automated Forces

differences in "color". The zoom lens model of attention currently has two resolutions, low and high. Perceptual grouping is dynamic and involuntary, although the pilot can also voluntarily group visual objects for tracking purposes. The perceptual attention model is integrated with Soar's decision cycle in a pilot that flies missions in a synthetic battlespace, complete with terrain and other entities, which include tanks, trucks, and dismounted infantry.

2.1.3 Selective Attention

To enable selective attention we added mechanisms to the pilot's perceptual system that provide the ability to focus on specific classes or types of entities, with the rest being filtered in earlier stages of the processing, prior to reaching the agent's working memory. These filtering mechanisms build directly on the staged approach to processing. Entities can be selected for attention based on the attributes of distance, color, group membership (e.g., member of proximally clustered group of vehicles), vehicle category (e.g., tank, helicopter, truck) or by specific vehicle type (e.g., T-70 tank, ZSU-23-2 air defense, AH-64 helicopter).

2.1.4 Zoom Lens

The selection mechanism is what enables the zoom lens effect – to get the big picture of the battlefield the pilot zooms out so that what it perceives arrives in working memory as a set of groups of vehicles that were clustered on the basis of proximity to one another. To get this view the pilot unsets all the selection criteria and only perceives groups, effectively filtering all the details. The groups themselves have attributes that may provoke an interest that results in zooming in on individual entities. For example, groups have attributes for center of mass and distance from the pilot. The nearest group often presents the greatest threat to safety, so the pilot may zoom in on individual members by selecting that group for attention. Once selected, the individual members of the group appear as perceptual input to the agent's working memory.

2.1.5 Top-down and Bottom-up Attention

The selection mechanism supports top-down form of attention – the pilot intentionally directs attention to the particular entities or groups based on the tactical situation. Bottom-up attention also plays an important role by making the pilot responsive to threats in the environment. Explosions, muzzle blasts, and weapon firing can all have an immediate effect on perception. Explosions serve to heighten awareness in the pilot, but there is entity associated with the percepts. Muzzle blasts, however, will cause the source entity to automatically appear in the pilot's working memory through perception. This bottom-up mechanism is customized for the military simulation domain. In some related research on virtual humans we are currently integrating a more general mechanism for bottom-up attention based on salience maps (Itti and Koch, 2000). Bitmap images are input to the salience maps, which detect contrasts in color, intensity, and orientation and combine their effects to predict where attention will be shifted. To take advantage of this bottom-up mechanism, however, it is necessary to graphically render the simulation and feed the image to the salience maps.

2.2 Comprehension

Perception is only the beginning of understanding. The perception module described here produces information about the location, velocity, orientation and some of the physical attributes of individual entities and at a more abstract level about groups. But when it comes to understanding a group's actions or its intentions, it is necessary to recognize the spatial and organizational patterns of the group. A shortcoming of earlier versions of the pilot was the inability to recognize the shape of groups. Groups were perceived as clusters of entities in the same proximity – a cluster has a center of mass, a bounding box, an entity count (or measure of density) and an aggregated velocity and orientation. What was lacking in perception was the ability to recognize and differentiate the formations of entities – the pilot could not tell the difference between a column of tanks and a wedge of tanks, a line of tanks and a staggered column. A formation can give an indication of the intentions of the force, whether it is attacking, defending, or simply moving from one area to another.

Besides interpreting a unit's tactical formation, it is also important to be able to infer its echelon and type. Discerning that a group is really a company of supply trucks may have a much different set of implications than if it is a battalion of tanks. Combining organizational information with tactical formation can lead to a clearer tactical understanding of the situation. For example, if the pilot sees a column of thirty tanks in a column on a road this indicates that a tank battalion is performing a road march to some destination. On the other hand, if the same thirty tanks were observed in a line formation advancing across an open field, then they are probably attacking. Or, if they are in a staggered line (which may conform to local terrain features) but not moving, their stance may be interpreted as defensive.

To achieve the goal of tactical understanding, we took a template-based approach to pattern recognition (Zhang and Hill, 2000a,b). This approach involved four steps: (1) constructing a template database, (2) building patterns of observed objects, (3) finding the best possible situation template, and (4) refining the patterns based on situation hypotheses and by collecting more data.

2.2.1 *Template database*

A template database was constructed from the ModSAF formation and echelon databases. The ModSAF formation database contains spatial layouts of units at the platoon and company level that are used in different tactical situations. The layouts are a convenience for ModSAF users who desire to rapidly instantiate units of vehicles in tactical formation – once the vehicle type and echelon are selected the user can specify a formation. ModSAF's echelon database contains information about the composition of different types of units at each echelon. For this study we focused on lower level echelons.

To construct a template database, we encoded tactical formations from the ModSAF database into individual templates. The template representation is based on the k-d tree data structure (Friedman et al, 1977), which has been widely used in many areas such as computational geometry and computer vision. This type of structure is specially designed to encode spatial information and there are efficient algorithms for matching kd-

trees to look for correspondences. The templates are indexed based on the types and quantities of entities contained in them.

2.2.2 Pattern building

The process of recognizing a situation begins by building a pattern, which is a structured representation of a set of sensed objects. Patterns are built by retrieving candidate templates from the database based on the perceived objects' types and quantities. With this set of pre-selected situation templates, the next step is to build a set of patterns of the observed objects, one pattern per template. Building a pattern based on a template involves creating such a pattern that is as similar to the tree structure stored in the template as possible, and then measuring the similarity between the pattern and the tree of the template. In building a pattern, the parameters of the tree of a template, such as the distances of entities and their spatial codes, are used as parameters to cluster the sensed entities and organize them into another tree structure. The algorithm for building a pattern works in a bottom-up fashion. It first retrieves the distance of the lowest-level cluster in the tree of a template, and uses the distance as the proximity parameter for clustering the perceived entities. Each set of clustered entities is stored in a subtree, with the root representing the cluster and its children the entities in the cluster. The algorithm recursively applies itself to the clusters, creating a set of clusters of clusters. The algorithm continues until one cluster is formed. The output of this step is a set of candidate hypotheses about the current situation.

2.2.3 Selecting the Closest Match

To identify the best hypothesis the algorithm measures the similarity between each pattern and its corresponding template and the similarities of all patterns need to be compared in order to choose the best one. In this work, we developed a domain-independent measuring method. The similarity of a pattern to its template is measured as follows. A mismatch between two nodes, one from the pattern and the other from the tree of the template, will incur a penalty. The penalty is greater if the nodes are higher in their trees, since a node higher in a tree represents an organization in a higher organizational hierarchy and a mismatch between two larger organizations will impose a bigger impact on the overall matching. In our system, we experimentally adjust a set of penalty weights for mismatches at different depths. In the end, the algorithm ranks the situation hypotheses based on their measure of similarity.

2.2.4 Hypothesis Refinement

The best hypothesis may not inspire a high degree of confidence if the measure of similarity is low. In these cases it may be necessary to collect more information, which is accomplished by looking around. Where the pilot looks and what information is sought will depend on the set of hypotheses that need to be either confirmed or disproved. We did not experiment with this process, but it would be the next logical step to take in this line of research. Thus, one of the motivations for visual search, which is an important perceptual process related to attention, is that it is driven by the need to refine hypotheses about the current situation.

2.3 Prediction

A pilot needs to be able to anticipate where to look when performing visually oriented tasks in a dynamic environment. This equates to an ability to make short-term predictions about the direction that a mobile agent will travel as it traverses complex terrain.. For a number of tasks, the pilot's visual attention is divided between tracking one or more vehicles and scanning the environment for information. To accomplish this involves shifting the pilot's gaze from the vehicle(s) being tracked to other objects in the environment. Reacquiring these highly mobile vehicles can be difficult when one's attention is momentarily diverted elsewhere. Looking away even for a few seconds can result in losing track of the vehicle since it can move hundreds of feet in a short time. To make it easier to visually reacquire a moving vehicle, we wanted to enable the pilot to make short-term predictions of where the vehicle will be located up to seven seconds in the future. With this prediction the pilot would be able to shift back his gaze to approximately the right place to reacquire the target object. But projecting the direction and location of a vehicle is not a simple matter—terrain features such as rivers and mountains, and cultural features such as roads and bridges, can strongly influence the path taken by a driver. We do not believe it is sufficient to predict a vehicle's location by making a simple linear projection. A driver may choose to turn at a road intersection or change direction to avoid a natural obstacle such as a lake or a steep mountain. Moving at 48 kilometers/hour, a vehicle can cover 100 meters in the short time the pilot glances away, or worse, the vehicle may change direction and end up someplace unexpected. In either case, the observer needs to reacquire the visual target with a minimal amount of search.

We hypothesized that the environment provides visual cues that can be used for making short-term predictions about a mobile agent's location without taking into account its goals or intentions. While knowledge of an agent's intentions may also be useful in making such predictions, that approach was not the focus of this study. Instead, we implemented a neural network that takes as input a set of terrain features in the vicinity of a mobile agent, and with this information it generates a probability vector that predicts the likelihood that the agent will travel in each of fifteen different directions. This is transformed into a prediction about the agent's future location, along with a time period that it is valid. We integrated the prediction capability with the perceptual system of our Soar-based helicopter pilot.

For this study we investigated the influence of seven terrain features: mountains, hard roads, soft roads, passable water, impassable water, buildings and forests. All of these features were available in a ModSAF terrain database—by querying a specific location in the terrain one can find out whether one or more of these features were present. Because of this way of storing information, we had to take samples of the areas of interest rather than doing an exhaustive query of the space.

We tested the system on a number of scenarios, including one where a tank follows a road through a mountain area with forests. The algorithm accurately predicts that the tank will follow the road. When we made a comparison of the actual and predicted locations over time—the points showed very little deviation and corresponded to the road shape.

This means that the road terrain feature affected the tank's movement and the pilot was able to accurately predict this movement.

Another general class of scenarios involves situations where the tank is travelling cross-country (i.e., it is not following a road). In one of these scenarios the tank came close to a river and had to find a bridge in order to cross it. As the tank drove within 300 meters of the river (blue box) the predictability decreased significantly. This was because the terrain database did not provide bridge information, so algorithm recognized that the river would moderate the tank's behavior, but it could not predict how. It eventually predicted that the tank would cross the river at a point where it was narrow. With the shorter prediction time it became necessary for the pilot to track the mobile agent more closely until it is in a place where predictions can be made more confidently.

Speed of the target object	Error
10 km/h	± 4 meters
20 km/h	± 8.5 meters
30 km/h	± 10 meters
48 km/h	± 15 meters

Table 1. Target Speed versus Error

We ran the algorithm on mobile agents moving at different speeds to test the accuracy of the predictions. The mobile agent's speed is assumed to be constant for any given prediction. Table 1 shows the maximum error between the predicted and actual positions. Given that the distance between the virtual pilot and the mobile agent ranged from 1 to 4 km, the pilot should have very little difficulty reacquiring their targets.²

3. Scientific, military, and commercial impact of accomplishments

Virtual humans, like real humans, need to perceive their environment. They need to be capable of processing perceptual information, focusing their visual attention, comprehending situations and the behaviors of others, and predicting where to direct their attention when tracking and reacquiring multiple objects. Humans develop a knack for directing their gaze toward the right objects at the right time—virtual humans need the same kind of ability. But for an increasing number of applications, a virtual human's gaze behaviors must go beyond serving situational perceptual needs—they must also be realistic-looking to human observers. This is particularly true in social situations, where the direction of one's gaze plays a significant role in the communication (Cassell and Vilhjalmsson, 1999; Argyle and Cook, 1976). This area of research will be fertile ground for developing and testing scientific hypotheses about human perceptual attention in virtual humans.

² We have only recently begun to test this hypothesis and this will be the subject of future work.

The impact on military applications is clear—there is an increasing interest in modeling human behavior and in the creation of virtual humans for mission rehearsal. We have addressed the issue of how to control a virtual human's perceptual focus using an intrinsic model of perceptual attention and cognition so that the resulting behavior is both realistic and believable. We also addressed how perception can support comprehension by mapping visual patterns onto doctrinal templates of unit tactical formations, and echelons for military domains.

In addition to military applications, this research will also potentially impact the development of virtual humans in commercial applications such as computer games, interactive narrative, and even motion pictures that use animated characters. In order to create a sense of immersion, computer games and interactive narrative both require realistic and believable behavior. There is a tension between what a model of perceptual attention can generate and whether it is believable when observed by a human. At one extreme, animated characters can portray a believable human character and yet have no autonomy or cognition at all. An example of believable characters with no cognition can be seen in the Final Fantasy movie—the behavior of these characters employ believable emotional expressions and gestures, but it is all driven by a human animator, who decides every nuance of the performance. The problem with this approach, however, is that characters cannot dynamically interact with the environment or with other agents. At the other extreme, a virtual human could potentially be developed with a very realistic model of perceptual attention, but fail to create a believable human character, since gaze behaviors are purely functional—they may be socially or emotionally moderated.

This work attempts to address the issue of believability and realism: (1) it is grounded in psychological theories of perception and cognition, especially concerning the control of attention and perceptual grouping. (2) It is more believable than current models from the standpoint of providing rich representations of the world while remaining computationally tractable.

4. Technology Transfer

Portions of this research have already been transferred to the research group at the University of Southern California's (USC) Institute for Creative Technologies (ICT). The ICT is building a virtual human for use in the Mission Rehearsal Exercise (MRE) Project. The perceptual system of this virtual human is being modeled after the work performed under this grant. Furthermore the work on situation awareness is currently being extended in two areas. First, we are investigating how to use saliency maps (Itti and Koch, 2000) as the underlying mechanism for bottom up attention in the agent's perceptual system. Itti's saliency maps detect differences in luminance, color, and orientation and will soon also detect motion. We have already integrated Itti's saliency map code into the virtual human and used it to analyze scenes from the Mission Rehearsal Exercise. The next research step will be to investigate how to integrate top-down, task-oriented attention with bottom-up attention. The second area where we are extending situation awareness is by enabling the virtual humans to build a cognitive map

of the space they have explored. The cognitive map is based on what is perceivable rather than being built from ground truth. This differs from many military simulations where the virtual humans plan from a map but cannot perceive anything in the environment except other entities. We have adapted an algorithm developed by Yeap and Jeffries (1999) for computing local representations of the environment based on the perceptual perspective.

5. ONR Database Statistics

Publications (See Appendix A for a detailed list publications and presentations)

0 - Number of Papers Published in Refereed Journals Supported by ONR

0 - Number of Books or Chapters Published Supported by ONR

7 - Number of Refereed Conference Papers Supported by ONR

1 - Number of Technical Reports & Non-Refereed Papers Supported by ONR

0 - Number of Patents Issued

0 - Number of Patents Pending

8 - Number of Presentations

1 - Number of Degrees Granted

PI/CoPI Information

	Women	Men
Minority	0	0
Non-Minority	0	1
Total	0	1

Grad Students Information

	Women	Men
Minority	0	0
Non-Minority	0	1
Total	0	1

Post Doctoral Information

	Women	Men
Minority	0	0
Non-Minority	0	0
Total	0	0

Awards

Dr. Randall W. Hill, Jr., University of Southern California Information Sciences Institute Best Paper Award for "Modeling Perceptual Attention in Virtual Humans." Eight Conference on Computer Generated Forces and Behavioral Representation, Orlando, FL, May 1999.

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R. Hill (2000a) Perceptual Attention in Virtual Humans: Towards Realistic and Believable Gaze Behaviors. *Workshop on Achieving Human-Like Behavior in Interactive Animated Agents*, Fourth International Conference on Autonomous Agents, Barcelona, Spain, June 4-6, 2000.

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W. Zhang and R. Hill (2000b). A Template-Based and Pattern-Driven Approach to Situation Awareness and Assessment in Virtual Humans. *Proceedings of the Fourth International Conference on Autonomous Agents*, Barcelona, Spain, June 4-6, 2000.

Appendix A – Research Grant Products

A1. Publications

1999

R. Hill (1999a). Modeling Perceptual Attention in Virtual Humans. *Proceedings of the 8th Conference on Computer Generated Forces and Behavioral Representation*, Orlando, FL, May 1999. (Best Paper Award)

R. Hill (1999b). Perceptual Grouping and Attention in a Multi-Agent World. *Proceedings of the Third International Conference on Autonomous Agents*, Seattle, WA, May 1999.

2000

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A2. Presentations

R. Hill (1999). Modeling Perceptual Attention in Virtual Humans. *8th Conference on Computer Generated Forces and Behavioral Representation*, May 1999, Orlando, FL.

R. Hill (1999). Modeling Perceptual Attention in Virtual Humans. *19th Soar Workshop*, May 21-23, 1999, Ann Arbor, Michigan.

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W. Zhang (2000). A Template-Based and Pattern-Driven Approach to Situation Awareness and Assessment. *20th Soar Workshop*, May 12-14, 2000, Marina del Rey, CA.

A3. Honors/Awards/Prizes

Randall W. Hill, Jr.

University of Southern California Information Sciences Institute

Best Paper Award for *Modeling Perceptual Attention in Virtual Humans*, Eight Conference on Computer Generated Forces and Behavioral Representation, Orlando, FL, May 1999. Awarded by CGF&BR Conference Program Committee.

A4. Students

Youngjun Kim received his M.S. in computer science and was accepted into the Ph.D. program while working on this grant.